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Salvage logging of mountain birch after geometrid outbreaks: Ecological context determines management outcomes

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ABSTRACT

Outbreaks of pest insects occasionally cause mortality of entire forest stands. Salvage logging of affected stands is the most common management response to such events. Logging may aid stand recovery by increasing the production and establishment of saplings, or stimulating the production of basal sprouts in sprouting tree species. However, the outcome of logging may depend on the ecological context in which it is implemented, with both herbivory and local growing conditions being potentially important factors. We conducted a field experiment to assess how logging affects recovery by saplings and sprouts in stands of mountain birch that have been damaged by outbreaks of geometrid moths. The study was conducted at the two locations Luftjok and Bugøyfjord in subarctic Norway, where moth outbreaks have caused widespread mortality of mountain birch during the last two decades. Logging generally caused a strong increase in the production of basal sprouts, and also improved sprout growth in Luftjok, resulting in a substantial production of new stems in the logging plots at this location within the six-year period of the study. In Bugøyfjord, sprout growth was retarded in logging plots compared to controls, resulting in complete failure to produce new stems during the study period. This appears to have been caused by ungulate browsing, possibly in interaction with regional, geologically determined, gradients in growing conditions. The outcome of logging also depended on local site quality, with limited sprouting occuring in rich meadow type stands, which traditionally have been assumed to have low capacity for sprout production. Birch saplings were less abundant in logging plots than in controls by the end of the study, especially in Bugøyfjord, suggesting that logging did not improve sapling production. We conclude that logging may stimulate damaged mountain birch stands to recover by means of basal sprouting, but that the positive effects of logging may be reduced by browsing in some areas. Logging should also be practiced with care in rich meadow type stands, which have limited capacity for sprouting.

1. Introduction

Outbreaks of defoliating or wood-boring insects dominate the natural disturbance regime in many forest ecosystems (Barbosa et al., 2012). Outbreaks can cause stand-wide mortality, and thereby produce rapid transitions in ecosystem state at the landscape level (Karlsen et al., 2013; Pureswaran et al., 2015). The spatial extent and impact of outbreaks is currently increasing in boreal and subarctic ecosystems due to climate-driven range expansions and human-assisted invasions of pest insects (Weed et al., 2013; Lovett et al., 2016). This is a growing concern from the perspective of both conservation and the ecosystem services provided by forests (Schowalter, 2012).

Apart from allowing the forest to recover naturally, the most common management response to stand-killing outbreaks is salvage logging of affected stands (Dale et al., 2001; Dhar et al., 2016). Logging can aid the recovery of the tree layer by increasing the establishment and growth of saplings. This may come about because more light reaches the forest floor after logging, and because logging-induced disturbance may expose mineral soil that is favorable for sapling establishment (Collins et al., 2011; Collins et al., 2012). Logging may also increase the production and growth of basal sprouts in trees species that are capable of this type of vegetative regeneration (Bond and Midgley,

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2001; Klimesová and Klimeš, 2007). Increased sprouting may occur because removal of dead stems activates dormant basal buds and frees up nutrients from the root system (Luostarinen and Kauppi, 2005). While logging has the potential to aid regeneration of the tree layer, it may also have negative impacts on biodiversity and forest resilience (Dhar et al., 2016; Thorn et al., 2017). It is therefore essential that decisions to implement logging are based upon solid empirical evidence for the expected benefits.

The mountain birch (*Betula pubescens* var. *pumila* L.) forest of northern Fennoscandian is a well-known example of a forest ecosystem that has experienced increasing disturbance from insect outbreaks in recent decades. Cyclic outbreaks of the defoliating geometrid (Lepidoptera: Geometridae) moth *Epirrita autumnata* Bkh. (autumnal moth) occur naturally in this region (Tenow, 1972), but climate warming has recently facilitated the expansion of more southern geometrids into areas historically occupied only by *E. autumnata* (Jepsen et al., 2008; Jepsen et al., 2011). This has resulted in increased defoliation pressure on mountain birch in many areas. Ten thousand km^2 of mountain birch forest was defoliated in northern Fennoscandia during 2000–2008 (Jepsen et al., 2009b), resulting in extensive mortality of birch forest in parts of the region. Another outbreak cycle of unknown spatial extent affected many of the same areas from 2013 and onwards (Klemola et al., 2016).

As a response to climate-driven changes in moth outbreak activity, local stakeholders in northern Norway have discussed, and to some extent promoted, salvage logging of damaged mountain birch stands, as a means of recovering firewood and speeding up regeneration of the tree layer. Logging is expected to induce more vigorous basal sprouting when dead stems associated with living root systems are removed. Logging may also protect the basal sprouts from rot that develops in standing dead stems and spreads down into the root system (Lehtonen and Heikkinen, 1995). In addition, a positive effect of logging on the establishment and growth of saplings cannot be ruled out. Empirical evidence for these potential benefits is currently lacking, however, and field tests are needed to confirm that logging will produce the expected results.

The outcome of logging in mountain birch forest is likely to be modified by two key environmental context factors, namely local growing conditions and herbivory. The mountain birch is a highly plastic species, and its growth form is linked to the quality of the local soil (Verwijst, 1988). Trees growing on poor soils tend to be polycormic (multi-stemmed) and usually produce stems of low stature and diameter. Trees on richer soils are more likely to be monocormic (single-stemmed) and tend to produce larger stems. Polycormic birches have high capacity for vegetative regeneration by production of basal sprouts, while the monocormic growth form has traditionally been assumed to regenerate mainly from seeds. The effects of logging in terms of sprout production may therefore be largest in polycormic stands.

With respect to herbivory, large mammalian herbivores in the form of moose (*Alces alces* Gray) and semi-domestic reindeer (*Rangifer tarandus* L.) are abundant across much of northern Fennoscandia, and impose strong limitation on the growth and survival of woody plants in the region (Van Bogaert et al., 2009; Speed et al., 2011; Ravolainen et al., 2014). Browsing by reindeer has also been shown to reduce survival of mountain birch saplings (Lehtonen and Heikkinen, 1995; den Herder and Niemela, 2003; Kumpula et al., 2011). In addition, Biuw et al. (2014) found that basal sprouts were almost absent in plots experiencing year-round grazing by reindeer in Finland, while sprouts were abundant in only summer-grazed plots on the Norwegian side of the border. This suggests that the intensity and/or seasonality of reindeer browsing has substantial impacts on the survival of basal sprouts in mountain birch, and raises the possibility that the effect of salvage logging may interact with herbivory.

In the present paper, we report from a field experiment that was established to test the effects of logging on the recovery of mountain birch stands via basal sprouts and saplings after mortality caused by a moth outbreak. After experimental logging, we monitor the development of key state-variables related to stand recovery – namely the number of basal sprouts and saplings, the length of the sprouts, and their recruitment into new stems – over a period of five consecutive years. We also monitor the presence of vertebrate herbivores in our experimental plots, and assess their impact on post-logging recovery dynamics by recording browsing marks on basal sprouts. To assess the importance of the ecological context in which the logging is implemented, we replicate the experiment in two separate geographic locations that differ in terms of geology and herbivore activity, and stratify our design according to local growing conditions within locations.

2. Materials and methods

2.1. Study system

The study was conducted in the Varanger region (70°N, 29°E) in the eastern part of Finnmark County, northeast Norway. Varanger is situated in a transition zone between northern-boreal deciduous forest and low-arctic tundra, where discontinuous stands composed almost entirely of mountain birch constitute the forest-tundra ecotone. Rowan (*Sorbus aucuparia* L.) and clonal stands of aspen (*Populus tremuloides* Michx.) also occur patchily. The climate of the region is sub-oceanic, with mean temperatures of 12.5 °C for July and −11.6 °C for January (1971–2000 normal period for Rustefjelbma meteorological station 70°23′55″N, 28°11′36″E). Annual precipitation is 400–500 mm.

Outbreaks by geometrid moths are the main natural disturbance factor in the north-Fennoscandian mountain birch forest (Tenow, 1972; Jepsen et al., 2009b). Outbreaks occur roughly every ten years, but vary greatly in amplitude and spatial extent. During the period 2002–2008, the Varanger region was affected by an unusually severe and prolonged outbreak, involving both the native *E. autumnata* and the recently invasive *Operophtera brumata* L. (winter moth). This resulted in historically unprecedented damage to the mountain birch forest throughout much of the region, with the stem mortality rate exceeding 95% in some areas. Further details about this outbreak are given in Jepsen et al. (2009b) and Jepsen et al. (2013).

2.2. Study design

Our field experiment was conducted at the two locations Luftjok (70°15′N, 28°21′E) and Bugøyfjord (69°53′N, 29°20′E). The forest at both sites was severely damaged during the 2002–2008 outbreak, but the timing of defoliation differed somewhat between the two sites. Judging from satellite-derived time series of changes in the normalized difference vegetation index (Jepsen et al., 2009a), Luftjok was defoliated mainly in 2003, 2005 and 2006, while Bugøyfjord was defoliated mainly in 2006–2008 (Appendix 1, Fig. S1). The two locations also differ substantially in geology. Luftjok is located on sedimentary bedrock composed of shale, sandstone and limestone, and has a well-developed soil layer. The bedrock in Bugøyfjord is metamorphic and composed mainly of gneiss, with a less developed soil layer (http://geo.ngu.no/kart/berggrunn/). This means that Luftjok has richer soil conditions and is more favorable for the growth of vegetation than Bugøyfjord.

During August of 2011, we laid out 20 experimental plots of 30 × 30 m at both Luftjok and Bugøyfjord. All plots had a minimum of 20 birch trees, and were located in forest with a high proportion of mature stems. This is representative for the age structure of the forest both within our two study locations and for the outbreak area as a whole. Half of the plots within each location were located in forest that was expected to have poor growing conditions (i.e. low site productivity) for the location in question (hereafter “poor forest”), while the other half was located in more favorable conditions (hereafter “rich forest”). The distinction between rich and poor plots was based on the